# Height Growth Prediction for Black Locust on Surface-Mined Areas in West Virginia



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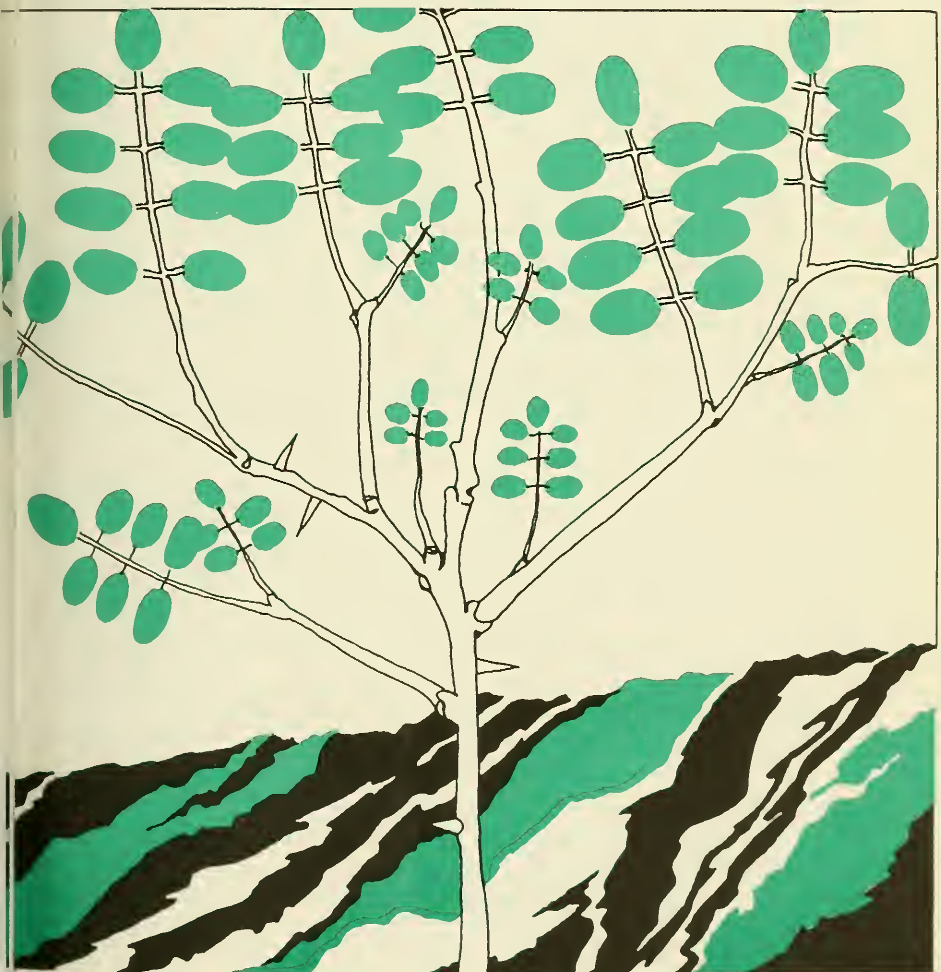

West Virginia University Agricultural Experiment Station

## Summary

Growth of black locust was studied on areas surface mined for coal in 26 counties in West Virginia. Heights and ages of trees were determined and site variables were measured, including slope per cent, aspect, slope position, position of the plot on the spoil surface, elevation and extent of regrading.

Multiple regression analyses showed that over 60 per cent of the total variation in height growth of black locust on the study areas was accounted for by four of the variables studied—slope per cent, aspect, elevation and extent of regrading. Using the multiple regression equation developed in the study, a table was constructed which can be used to estimate the average annual height growth of black locust on unplanted surface-mined sites.

### AUTHOR

James H. Brown was associate professor of silviculture and associate silviculturist, West Virginia University Agricultural Experiment Station, when this research was conducted. He is now with the Ohio Agricultural Research and Development Center, Wooster, Ohio.

WEST VIRGINIA UNIVERSITY
AGRICULTURAL EXPERIMENT STATION
COLLEGE OF AGRICULTURE AND FORESTRY
R. S. DUNBAR, JR., DIRECTOR
MORGANTOWN

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JAMES H. BROWN

OVER 200,000 acres of land have been directly affected by surface-mining for coal in West Virginia and approximately 10,000 acres are being added to is figure annually. Initially, spoil banks formed during stripping operations are are of vegetation. Washing and runoff of water from these areas may result in rosion, stream pollution, and landslides and slips. Revegetation offers the most ractical means of stabilizing surface-mined lands and returning them to a pro-uctive condition.

Black locust (*Robinia pseudoacacia* L.) has several characteristics which ake it ideal for providing cover and stabilization on spoil banks. It is fast rowing, has a spreading crown, produces seed at an early age, and puts down rge amounts of litter. It sprouts prolifically from the root system, further dding to the number of trees on the site. It also is a legume and adds nitrogen the spoil material. This is especially important since nitrogen is one essential lant nutrient which is deficient on newly formed spoil banks. Because of this tter factor, the spoil surface under black locust stands is often covered with a eavy growth of herbaceous plants and these provide additional stabilization on e site.

The rapidity with which black locust stands cover and stabilize surface-ined areas depends to a large extent on the growth rate of the trees and the acing between stems. If growth is rapid, trees established at six- to seven-foot tervals can be expected to give crown closure within three or four years after stablishment. On those areas where growth is slow, trees at comparable spacings ay not give complete crown cover of the spoil surface until six to ten years fter establishment (Brown and Tryon, 1960; Brown, 1962). Therefore, when tands are established specifically for the purpose of providing stabilization and over on spoil bank sites, spacing between trees can be regulated to provide over within a certain period of time.

The purpose of this study was to evaluate the effects of site factors on the rowth of black locust on surface-mined areas and to develop a practical and seable system for predicting growth potential on newly formed, un-planted poil banks.

## Procedure

Data used in this study were originally collected during the course of tw other studies (Brown and Tryon, 1960; Brown, 1962). Individual spoil bank sit throughout West Virginia were randomly selected for sampling (Table 1). In th first study using areas direct seeded with black locust, four sampling lines we randomly located on each spoil bank. Along each of these lines, seven plots we randomly selected—three on the reverse terrace or bench area, three on the out slope area, and one at the breaking point between the reverse terrace and out slope. On each plot where a black locust was growing, total height and age

**TABLE 1**

**Distribution of sample plots in study of black locust growth on surface-mined areas in West Virginia.**

| County | Number of Separate Spoil Banks Sampled | Number of Sample Trees |
|---|---|---|
| Barbour | 3 | 20 |
| Boone | 5 | 37 |
| Braxton | 1 | 8 |
| Brooke | 2 | 9 |
| Clay | 1 | 2 |
| Fayette | 14 | 92 |
| Grant | 1 | 5 |
| Greenbrier | 7 | 40 |
| Harrison | 1 | 4 |
| Kanawha | 5 | 32 |
| Logan | 1 | 8 |
| McDowell | 6 | 40 |
| Mercer | 6 | 31 |
| Mineral | 1 | 7 |
| Mingo | 4 | 35 |
| Monongalia | 2 | 3 |
| Nicholas | 4 | 30 |
| Ohio | 1 | 2 |
| Pocahontas | 2 | 9 |
| Preston | 7 | 42 |
| Putnam | 2 | 10 |
| Raleigh | 12 | 78 |
| Randolph | 5 | 22 |
| Tucker | 3 | 12 |
| Webster | 3 | 23 |
| Wyoming | 3 | 20 |
| TOTAL | 101 | 622 |

ach tree were determined. In the second study using areas planted with nursery grown black locust seedlings, sample points were randomly located in each planting and the total height and age of each tree were determined.

In addition to heights and ages of sample trees, the following site data were determined for each plot:

1. Aspect: orientation was measured with a hand compass, facing down slope and across the plot and recorded as the azimuth from $0^{o}$ to $360^{o}$.

2. Slope per cent: steepness of the slope was measured in per cent with an Abney hand level.

3. Slope position: spoil area was located in the field as occurring on the lower, middle, or upper slope.

4. Position of plot on the spoil bank: each plot was located in the field as occurring on the reverse terrace, outer slope or break area between the reverse terrace and outer slope. The break area is much like a small ridge top, receiving only moisture which falls directly on the site. It was believed that, all other factors being equal, this was potentially the driest portion of the spoil bank site. Outer slopes were rated as intermediate in moisture because they potentially receive mositure which falls directly on the area as well as some drainage from the spoil surface above. The reverse terrace (bench area) was rated as the most moist portion of the spoil because it receives moisture which falls directly on the area, drainage from the spoil surface above, and drainage from unstripped areas above the surface-mined site.

5. Extent of regrading and resultant compaction: rated qualitatively in the field as little or no regrading, moderate regrading, and severe or heavy regrading.

6. Elevation: determined from topographic sheets and recorded to the nearest hundred feet.

After the data had been complied, growth of individual black locust trees was converted to average growth per year by dividing total height by age of the tree. This assumes that there is a linear relationship between growth and age of trees in the age classes sampled (3 to 12 years). This assumption was found to be statistically valid in analyses of data in the two original studies.

Since trees had been established using two different planting methods, values for average growth per year for trees established by each technique were compared and no significant difference was found. Therefore, all data were grouped for use in final analyses.

Multiple regression analyses were run at West Virginia University using the IBM 360 Computer. This permitted computation of coefficients of multiple determination ($R^2$) for a number of equations, allowing for screening of each independent variable, alone and in combination with other independent variables. Initial tests were conducted using data as recorded in the field. Data were then graphed to examine each independent variable in relation to average growth per year. In these analyses, data for elevation and aspect showed trends

which indicated that better relationships would be obtained if rating systems or transformations were used instead of actual values recorded in the field. There were no significant changes in growth of black locust up to elevations of approximately 2,500 feet (from 800 to 2,500 feet for areas sampled in the study). Above 2,500 feet, growth decreased consistently as elevation increased. Therefore, elevation classes were grouped as follows for use in subsequent analyses: elevations up to 2,500 feet; 2,501 to 3,000 feet; 3,001 to 3,500 feet; above 3,500 feet (from 3,501 to 4,200 feet for areas sampled in the studies).

Azimuth values were examined and grouped into three classes: moist aspects, with azimuths from 0 to 90 degrees (north to east); intermediate or neutral aspects, with azimuths from 90 to 180 degrees (east to south) and 270 to 360 degrees (west to north); and dry aspects, with azimuths from 180 to 270 degrees (south to west). Such groupings for purposes of evaluating the effects of aspect on tree growth have been used successfully in a number of other studies (Trimble and Weitzman, 1956; Yawney, 1964; Beers *et al.*, 1966; Yawney and Trimble, 1968; Hartung and Lloyd, 1969).

# Results

Growth of black locust on surface-mined areas was found to be highly correlated with slope per cent, aspect, elevation, and extent of regrading (compaction) of the spoil surface. Location of the spoil bank on the hillside (slope position) and position of the plot on the spoil area did not contribute significantly to the regression equation (Table 2).

The regression equation derived is as follows:

$$Y = 4.123 - 0.366(X_1) - 0.018(X_2) - 0.204(X_3) - 0.624(X_4)$$

where:

$Y$ = average height growth per year, in feet.

$X_1$ = elevation class:
- 0 = Up to 2,500 feet
- 1 = 2,501 to 3,000 feet
- 2 = 3,001 to 3,500 feet
- 3 = Over 3,500 feet

$X_2$ = Slope per cent

$X_3$ = Aspect class:
- 0 = Northeast: azimuths from 0 to 90 degrees (north to east)
- 1 = Northwest and Southeast: azimuths from 270 to 360 degrees (west to north) and 90 to 180 degrees (east to south)
- 2 = Southwest: azimuths from 180 to 270 degrees (south to west)

$X_4$ = Extent of regrading (compaction):
- 0 = No or light regrading
- 1 = Moderate regrading
- 2 = Heavy or severe regrading

TABLE 2

Significance of independent variables affecting growth of black locust on surface-mined areas.

| Variable | "t" Value for Partial Regression Coefficient | Simple Correlation Coefficient with "Y" | Per cent of Total Variance Explained by Variable |
|---|---|---|---|
| Elevation | -20.01* | -0.46* | 20.9 |
| Slope per cent | -23.32* | -0.16* | 23.8 |
| Aspect | - 8.76* | -0.30* | 3.3 |
| Regrading | -32.78* | -0.38* | 15.3 |

*Significant at the 1 per cent level.

The coefficient of determination ($R^2$) for the equation is 0.633 and the regression is significant at the 1 per cent level. The standard error of estimate is $\pm$0.376 feet with the average growth per year of 2.476 feet, or approximately $\pm$15 per cent.

Data for use as a field guide in estimation of expected growth of black locust on unplanted spoil banks were computed using the regression equation and are presented in Table 3.

# Discussion

## VARIABLES INCLUDED IN PREDICTION EQUATION

Of the four factors included in the final regression equation, steepness of slope accounted for the greatest amount of variation in growth of black locust ($R^2$ = 0.238). This factor has been found to be important in affecting growth of a number of tree species, particularly in mountainous areas such as West Virginia, and slope per cent has been included in a number of other growth prediction equations (Trimble and Weitzman, 1956; Yawney, 1964, Yawney and Trimble, 1968). Since surface runoff increases with increasing grade, slope indirectly affects the moisture available for growth of tree species. On surface-mined areas grades of 70 per cent or more occur frequently.

The effects of elevation ($R^2$ = 0.209) on growth of black locust can best be attributed to the growth habit of the species. Black locust has an indeterminate growth habit, beginning height growth in spring after the last killing frost and continuing at least limited height growth until a killing frost occurs in the fall. Since the length of the frost-free growing season becomes shorter at higher elevations, growth of black locust is affected accordingly. It could not be determined why this reduction in growth occurred only at elevations above 2,500 feet for the plots included in this study. It is possible that some critical temperature was reached at approximately this elevation.

TABLE 3

Estimated average annual height growth of black locust on surfaced-mined areas in West Virginia as related to slope, aspect, elevation and extent of regrading.[1]

| Slope Per cent | Aspect | Average Annual Height Growth at Elevation of Up to 2,500 feet | 2,501 to 3,000 feet | 3,501 to 3,500 feet | Over 3,500 feet |
|---|---|---|---|---|---|
| AREAS WITH LITTLE OR NO REGRADING | | | | | |
| 0 | - | 4.1 | 3.8 | 3.4 | 3.0 |
| 20 | NE | 3.8 | 3.4 | 3.0 | 2.7 |
| | NW & SE | 3.6 | 3.2 | 2.8 | 2.5 |
| | SW | 3.4 | 3.0 | 2.6 | 2.3 |
| 40 | NE | 3.4 | 3.0 | 2.7 | 2.3 |
| | NW & SE | 3.2 | 2.8 | 2.5 | 2.1 |
| | SW | 3.0 | 2.6 | 2.3 | 1.9 |
| 60 | NE | 3.0 | 2.7 | 2.3 | 1.9 |
| | NW & SE | 2.8 | 2.5 | 2.1 | 1.7 |
| | SW | 2.6 | 2.3 | 1.9 | 1.5 |
| 80 | NE | 2.7 | 2.3 | 2.0 | 1.6 |
| | NW & SE | 2.5 | 2.1 | 1.7 | 1.4 |
| | SW | 2.3 | 1.9 | 1.5 | 1.2 |
| 100 | NE | 2.3 | 2.0 | 1.6 | 1.2 |
| | NW & SE | 2.1 | 1.8 | 1.4 | 1.0 |
| | SW | 1.9 | 1.5 | 1.2 | 0.8 |
| AREAS WITH MODERATE REGRADING[2] | | | | | |
| 0 | - | 3.5 | 3.1 | 2.7 | 2.4 |
| 20 | NE | 3.1 | 2.8 | 2.4 | 2.0 |
| | NW & SE | 2.9 | 2.6 | 2.2 | 1.8 |
| | SW | 2.7 | 2.4 | 2.0 | 1.6 |
| 40 | NE | 2.8 | 2.4 | 2.0 | 1.7 |
| | NW & SE | 2.6 | 2.2 | 1.8 | 1.5 |
| | SW | 2.4 | 2.0 | 1.6 | 1.3 |
| AREAS WITH HEAVY OR SEVERE REGRADING[2] | | | | | |
| 0 | - | 2.9 | 2.5 | 2.1 | 1.8 |
| 20 | NE | 2.5 | 2.1 | 1.8 | 1.4 |
| | NW & SE | 2.3 | 1.9 | 1.6 | 1.2 |
| | SW | 2.1 | 1.7 | 1.4 | 1.0 |
| 40 | NE | 2.2 | 1.8 | 1.4 | 1.1 |
| | NW & SE | 2.0 | 1.6 | 1.2 | 0.9 |
| | SW | 1.7 | 1.4 | 1.0 | 0.7 |

[1]Black locust normally undergoes a period of slow growth during the first year after planting. Data presented is expected growth after this establishment period, normally during the second and subsequent years.

[2]Regrading of spoil areas sampled was confined to slope of 40 per cent or less.

The effects of compaction by regrading also contributed very significantly ($R^2 = 0.153$) to the variation in growth of black locust on surface-mined areas. There is usually little or no aggregation of soil-sized particles in spoil materials and as a consequence these materials are easily compacted. This may have several important implications. It is common practice to do substantial regrading in the reclamation of many surface-mined areas. In fact, regrading is required by law on certain sites in many states, including West Virginia. However, this study indicates that this practice can be detrimental to the growth of black locust. On the other hand, lack of regrading could also create problems, for regrading reduces slopes, particularly on reverse terrace or bench areas and, as noted previously, growth decreases as slope increases. Thus, the most desirable practice would seem to be one that uses light regrading. It would also be beneficial if regrading could be confined to periods when spoil material is relatively dry.

Aspect, the fourth factor included in the regression equation, contributed a much smaller but still significant amount to the overall variance in growth of black locust ($R^2 = 0.033$). As with slope, aspect indirectly affects the amount of moisture available for plant growth. Temperatures and evaporation losses are greatest on southwest facing slopes and lowest on northeast aspects.

## IMPORTANCE OF SOIL VARIABLES NOT INCLUDED IN PREDICTION EQUATION

Despite the fact that only four variables were included, a relatively high percentage (63.3 per cent) of the total variation in growth of black locust on surface-mined areas was accounted for by the final regression equation. This may seem surprising, particularly in view of the fact that a number of important site factors are not directly accounted for in the equation. Notable among these are soil factors which have often been included in other systems developed for predicting growth of tree species.

Soil variables were not included in this particular study for two primary reasons. First, the objective of the study was to develop a practical and useable system for predicting growth of black locust on newly formed, unplanted spoil bank areas. Many persons who might find use for such a system have not had training in the evaluation of soil factors and might have difficulty in using the system if such variables were included. Secondly, spoil materials formed during surface mining vary considerably from undisturbed soils. A normal, undisturbed soil has developed over a long period of time in response to the effects of parent material, topography, and climate. Such soils may be relatively uniform over a considerable area so that measurements taken at some particular point may be extrapolated to apply to a relatively large area. On the other hand, spoil banks are composed of a heterogenous mixture of rock fragments and slabs, intermixed with varying amounts of finer rock particles and soil-sized material. There is usually considerable variation in these materials within relatively short distances. Thus, soil analyses at a particular point may not be indicative of conditions over a sufficiently large area to make such measurements meaningful and useful.

Although soils data were not included in regression analyses in this study, omission of such data may not be a particularly serious problem. Spoil analyses were available for approximately 20 per cent of the plots used in the study and these analyses give some insight into characteristics of spoil material for all areas sampled. Although textures ranged from coarse (loamy sand) to fine (clay), over 80 per cent of the samples fell into the medium textural classes (loam, silt loam, clay loam, and silty clay loam). The average texture was a clay loam. Thus, a relatively narrow range of favorably textured spoil materials were encountered on most of the spoil areas for which samples were available.

Studies, including the two in which the data used in this study were originally collected, have shown that spoil acidity (pH) is extremely important in affecting establishment and growth of vegetation on surface-mined areas. Black locust will generally not grow on areas having acidity values below pH 4.0. For those plots for which analyses were available, pH ranged from 4.1 to 6.7. Approximately 80 per cent had values from 4.0 to 5.9 and over 55 per cent fell into the narrow range from pH 4.5 to 5.5. This is not to say that the areas included in the original samples had no spoil material with pH below 4.0. Rather, black locust were not found growing on plots having spoil material with low pH. It is reasonably certain that all of the sample plots included for use in this study had spoil material with pH of approximately 4.0 and above. In view of these factors, it is obvious that the system developed in this study for estimation of potential growth on unplanted spoil bank areas can be used **only on areas having nontoxic spoil material**—areas with pH of approximately 4.0 and above. On areas with pH below 4.0, little or no survival of black locust or other vegetation can be expected.

Soil depth, another factor commonly used in developing systems for predicting growth of tree species, was probably not limiting on spoil areas. Although depths of spoil materials were not estimated for each plot in the field, observations would indicate that total depths on most plots exceeded five feet and in many cases ran up to thirty feet and more. This greatly exceeds the depths of three feet and less which are commonly encountered in working with normal, undisturbed soils in West Virginia.

## USE OF PREDICTION SYSTEM ON UNPLANTED SURFACE-MINED AREAS

With nearly two-thirds of the total variation in growth of black locust accounted for by the four-variable equation developed in this study, Table 3 should provide a fairly reliable guide for estimating potential growth on nontoxic (pH 4.0 and above), unplanted spoil bank areas. Since stabilization and cover are the primary purposes of most black locust plantings on spoil areas, it is important that this objective be achieved in a relatively short period of time.

Rate of growth of black locust is of primary importance in affecting this stabilization process. Partial crown closure will occur at an earlier age and litter

production, root sprouting and nitrogen fixation will take place at higher rates on those areas where growth is rapid than on areas where growth is relatively slow.

Field observations indicate that black locust normally undergoes an establishment period the first year after planting or direct seeding during which growth is slow. After this, growth usually proceeds in response to characteristics of the spoil bank site—that is at rates similar to those shown in Table 3. Other measurements (Brown and Tryon, 1960) indicate that in the age classes sampled in this study (3 to 12 years), black locust crowns are approximately 60 to 70 per cent as wide as the height of the tree. Most stands undergo an establishment period the first year after planting. If trees are planted at a six-foot spacing between rows, partial crown closure is likely to occur during the third growing season on areas where growth is approximately four feet per year. Crown closure would occur during the fourth growing season where growth is two feet per year, and during the sixth growing season on areas where growth is only one foot per year. Thus, where growth will be rapid, six- to eight-foot spacings could be used with good results, while on areas where growth is expected to be slow, spacings could be reduced to four to five feet to obtain the desired stabilization and cover.

Table 3 may also be used as a guide for another purpose. Damage to black locust stands by the locust borer (*Megacyllene robiniae*) is closely related to the vigor of the trees. Where growth is slow, damage is often severe, while damage is greatly reduced in those stands where growth is rapid. Table 3 could serve as a guide for delineating those spoil bank areas where growth would be rapid and where post and prop production could be combined profitably with stabilization of surface-mined areas.

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